The Elizabethtown Bridge

H. G. TYRRELL
Chief Engineer

The Elizabethtown Bridge

Highway Bridge

over

The Miami River

at

Elizabethtown, Ohio

The Longest Simple-Truss Span

Price $1.00

DESIGNED BY

H. G. TYRRELL, CHIEF ENGINEER

AUTHOR OF

MILL BUILDING CONSTRUCTION.

THE ELIZABETHTOWN BRIDGE, H. G. TYRRELL, ENGINEER

INTRODUCTION

THIS account of the design and construction of the Elizabethtown bridge, has been prepared in response to numerous inquiries. Several years have elapsed since the bridge was completed and until now time has not permitted me to write any description. Brief mention of the work has been made in several of the technical journals, among which are The Iron Age, The Canadian Engineer, The Railway and Engineering Review, and others. No comprehensive description has, however, appeared.

Little or no mention is made in this description of the inspection, tests or erection, nor is there any sheet of details included.

As the bridge is the longest truss bridge span in existence, it will continue to be of special interest, at any rate until such time as its length is exceeded. It is possible that at some future time, the account may be revised and enlarged.

H. G. TYRRELL.

540 JUDSON AVE.
EVANSTON, ILL.

Evanston, Illinois, February, 1909.

Highway Bridge over the Miami River at Elizabethtown, Ohio

THIS bridge is remarkable in being the longest simple-truss span in existence. It has a span of 586 feet between centers of end pins and surpasses in length by 36 feet the longest other span, which is one in the bridge crossing the Ohio River at Cincinnati, known as the Cincinnati and Covington railway and highway bridge.

The Old Bridge. On the site of the present new steel bridge, there had been for many years an old covered wooden bridge, known locally as "Lost Bridge." It consisted of three spans, 195 feet long each, supported on stone piers and abutments. The old piers were unusually heavy, and yet, notwithstanding this fact, the foundation beneath them was badly scoured, so much so that one had fallen several feet out of plumb at the top. The superstructure of the old wooden bridge was also rapidly failing, and the spans showed excessive sag, a condition frequently developing in old wooden bridges before failure. In the summer or autumn of 1903 the superstructure of the old bridge was destroyed by fire, and the need of replacing it at once became apparent.

Type and Length of New Bridge. In selecting the most suitable type of bridge for replacing the old one, there were numerous important considerations. The rise and fall of the water in the Miami River is very uncertain. At flood seasons it rises rapidly, sometimes 20 feet or more in a few days. The greatest difference between high and low water is about 30 feet. At such times the last ten feet or more of rise is back water from the Ohio River. For this reason all bridges in this district are built at about the same elevation of 30 feet above low water of the Ohio River. The railroads and many of the highways

are likewise built on banks at the same elevation, for at flood seasons the entire country around is liable to be covered with water.

At another river crossing, about a mile distant from Elizabethtown, the conditions had been met in previous years by building a suspension bridge of 500 feet clear span, spanning the entire width of the water course. The suspension bridge is quite an imposing structure and an ornament to the district, but is lacking in the more important requirement of rigidity. It has a clear roadway of 20 feet and the stone towers at either end are placed 36 feet apart, so the cables have a considerable cradle. It has, also, six sets of stay cables from the towers to the floor, and is braced laterally by three sets of rod guys at each end, fastened to stone blocks on the river bank, yet the passage of ordinary loads, such as farm wagons, causes excessive vibrations. In high, or even moderate winds, the swaying of the bridge is also considerable.

At New Baltimore, Ohio, in the same county, similar conditions had been overcome by building a single truss span 465 feet in length, which was described in Engineering News, October 16, 1902.

The railroads were also having difficulty with their bridges in the same region, and some such bridges were destroyed by having their piers undermined by the scour and wash of the uncertain currents and soil. At the time when the rebuilding of the Elizabethtown bridge was being considered, a railroad bridge in the vicinity was being strengthened and the piers protected at great expense, by having large quantities of broken stone and loose rock deposited around the piers and abutments. It was found, however, that notwithstanding the dumping in of many carloads of rock, and the strengthening of piers with additional concrete, the river piers were still in an uncertain condition and frequently exposed to the damaging influences of scour and the shifting of the channel.

For these reasons it was decided to avoid the use of river piers in rebuilding the bridge at Elizabethtown, and to bridge the entire waterway with a single span. Having thus decided on the use of a single span, approximating 600 feet in length,

it then became necessary to select the most suitable type of bridge.

The suspension bridge described above is in some respects very desirable, but on account of its lack of stiffness was not seriously considered as a type for Elizabethtown. The underneath clearance would not permit the use of a deck arch of so long a span, and a through arch, such as those used at Bonn or Dusseldorf, or more recently at Bellows Falls, Vermont, are lacking in lateral stiffness. In through arches such as those mentioned above, it is necessary, in order to maintain the required clearance through the bridge, to omit top lateral bracing between the arch ribs for some considerable distance back from the springs. This is more serious than in truss bridges, where the end posts incline at an angle of 45 degrees or more with the horizontal. With the through arch the slope of the ribs is so gradual that a large part of the most effective lateral bracing between the ribs must necessarily be omitted.

Some forms of stiffened suspension bridge, and a cantilever design of 600 feet span between piers, with back stays similar to the back stays of a suspension bridge, were also considered. None of these forms were favored, chiefly because of their lack of stiffness. Of the alternate forms considered, the cantilever above referred to would doubtless have given the best results. It would leave the waterway entirely free of piers and would permit the use of a narrower roadway, by placing the trusses further apart at the shore, than at the end of the cantilever arms. It is interesting to note that a bridge of this type has since been built at Long Lake, N. Y., and is described in the Engineering Record of September 29, 1906.

After due consideration of various types, it was decided to use a through, pin connected, simple-truss bridge.

Invitation for Tenders. The bridge was being built by Hamilton County, and advertisements were therefore printed, calling for separate tenders for substructure and superstructure. The advertisement gave the length of span as 586 feet between centers of truss bearings and called for competitive plans and bids to be submitted.

Substructure Tenders. In response to the advertisements, tenders for building and repairing the substructure were received from five competing firms, which are given below:

	No. 1	No. 2	No. 3	No. 4	No. 5
Forming bank, cu. yd..	$ .35	$ .30	$ .40	$ .40	$ .38
Excavation, per cu. yd.	1.50	.90	1.00	1.00	.90
Crushed stone, pr cu.yd.	1.80	1.20	1.80	1.80	1.75
Screenings, per cu. yd.	1.80	1.20	1.80	1.80	1.75
Lumber, per M.......	60.00	40.00	50.00	40.00	40.00
Rolling, per sq. yd....	.05	.01	.05	.05	.05
Piling, per lin. ft.....	.50	.37	.50	.30	.50
Concrete, per cu. yd...	9.00	10.00	8.00	8.00	8.00
Sheet piling, per M....	15.00	10.00	15.00	13.00	12.40
Bridge seat beams....	1500.00	1000.00	1495.00	600.00	1500.00
Steel rods, per lb.....	.04	.035	.05	.03	.045
Puddling, per cu. yd...	2.00	2.00	2.00	2.00	2.00

The foundation work consisted chiefly in repairing the old stone abutments by building up new material in reinforced concrete in front of the old stone work, carrying up the retaining walls and parapets, and rebuilding the bridge seats with lines of steel beams embedded in concrete.

As this part of the work presented no unusual difficulty, or was not of particular interest, details of the substructure are not given. It will be interesting, however, to note that the presence of the old piers was some considerable assistance during erection. The steel work was assembled and erected on timber false work at low water season.

Superstructure Tenders. Competitive plans and prices were received from eighteen different firms for the design, construction and erection of the superstructure, with the result that the design prepared by the writer was accepted and the contract was awarded accordingly.

Description of Accepted Design. In preparing a design several comparative estimates were made, differing principally in the depth of truss, number of panels, design of floor system, and live loads. A summary of these estimates is as follows:

Comparative Estimates for Elizabethtown Bridge.

Plan	No. of Panels	Width of Road	Joist		Dead Load per ft.	Live Load per ft.	Steel tons	Estimated Cost	Cost plus 25%
A	22	30′	10″ I's	2′ apart	3,480	2,400	920	$68,000	$85,000
B	22	30′	12″ I's	3′ apart	2,710	1,200	686	53,000	66,200
C	18	30′	7″ I's	3′ apart	2,304	1,000	560	39,700	49,500
D	18	30′	3″x14″	3′ apart	2,122	1,000	514	37,700	47,100
E	18	30′	15″ I's	5′ apart	2,358	1,000	554	39,600	49,400
F	18	30′	15″ I's	3′ apart	2,442	1,000	604	41,900	52,400
G	24	30′	10″ I's	3′ apart	2,438	1,000	607	42,800	53,500
H	24	30′	12″ I's	5′ apart	2,488	1,000	591	42,500	53,100
K	24	30′	6″ I's	3′ apart	2,445	1,000	601	43,400	54,200
L	18	30′	7″ I's	2.5′ ap't	2,590	1,000	643	45,200	56,500
M	24	35′	10″ I's	3′ apart	3,500	1,500	867	68,900	86,100
N	24	35′			3,144	1,000	769	60,900	76,100
O	18	35′	6″ I's	3′ apart	3,092	1,400	713	57,300	71,600
P	24	30′	10″ I's	2′ apart	2,825	1,000	710	50,400	63,000

The center truss depth in all designs from A to L, inclusive, was 80 feet; also for design P; while M and N are 87 feet, and O, 75 feet deep.

In designs K, L and O, it will be seen that six- or seven-inch steel joist are used, while in all other designs much larger beams are required. The ability to use smaller joist is plainly due to the shorter panels of the floor system. Comparative estimates were made to ascertain the relative economy between using a larger number of short truss panels and a smaller number of longer truss panels, with intermediate floor beams in each panel, carried on heavy side girders. The comparisons clearly showed the economy of longer truss panels. Design L was therefore selected as providing the economy of long panels in the trusses and at the same time short panels, and correspondingly small joist for the floor system. Diagrams 7 to 12 inclusive, illustrate the various designs considered by the writer, No. 12 being the selected one, and the outline on which the bridge is built. The width selected for the roadway was 30 feet, and as the end posts and top chords are 30 inches wide, the distance between centers of trusses is 32 feet 6 inches, which is one-eighteenth of the entire span. The trusses are

divided into 18 panels, 32 feet 6 inches long each, making square panels for the lateral system. The type of truss is the subdivided Pratt, with main panels 65 feet long. The depth of truss varies from 80 feet at the center to 40 feet at the first panel point. The curve of the top chord is a parabola, in straight sections of two panel length. Stiff laterals and sway bracing are used throughout. This is a very essential feature of the design, and one upon which much of the stiffness of the bridge depends. Lateral and other light struts are built in box form, latticed on all four sides. The first panel of diagonals in the top lateral system are built in the same way. Each of the 32-feet-6-inch panels of the floor system are again subdivided by carrying an intermediate floor beam on two longitudinal beams, one at each side of the bridge. In addition to the benefit of economy in floor framing, the two side beams serve also as chords for the lower lateral system. The longitudinal and cross floor beams are of the same size, and diagonal laterals are rigidly connected by plates, which fasten to the bottom flanges of both cross and longitudinal beams. The floor joist consist of 6-inch steel beams, spaced 2 feet 6 inches apart, elevated on 9-inch beam corbels. On the steel joist is laid the 2½-inch oak flooring, spiked to six lines of 3x7 oak spiking pieces, with 60d nails. The wheel guards are 6x6-inch oak, beveled on the inner edge and elevated on 4 inch blocks, spaced 2 feet apart for drainage. The bridge was given an initial camber at the center of 3 feet. On each side of the roadway there is a neat railing, made of four angles latticed in box form. This railing lines up with the inner face of the web posts and fastens to them. The portal, as shown on the writer's design, is a heavy lattice framework, but it was changed in the shop to one of plate construction. This change was plainly a mistake, as it does not in any way harmonize with the light framing of the bridge. The lack of harmony of the portal with the rest of the bridge shows very clearly in the photographic view.

The two side lines of heavy floor stringers, which act also as wind truss chords, are rigidly attached by means of bottom bracket angles to the main truss posts. Such portions of the wind chord stresses as are not resisted by these longitudinal

side beams, are transferred to the bottom chord eye bars, through these rigid connections.

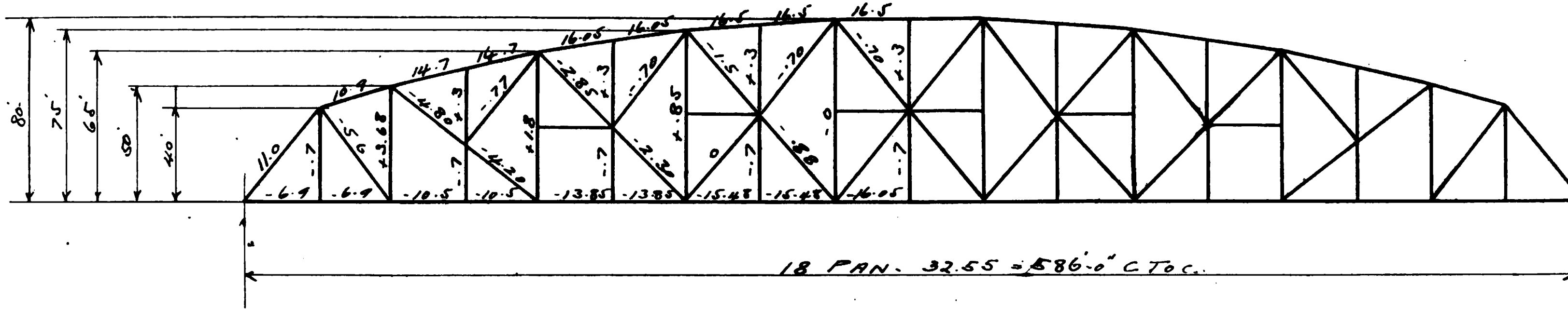
The cross beams, at the panel points, are suspended by two rod hangers 1½ inches in diameter each, from the bottom chord pins, and at the same time they are riveted to the bottom angles on the web posts. This gives a rigid floor beam connection and at the same time reduces the cost of erection. At one end of the bridge are sets of turned rollers, and at both ends the heavy side beams are connected to the shoe boxes, thereby transferring the wind strains as directly as possible to the masonry. The vertical posts are spliced at the joints of the lateral struts. The minimum thickness of metal used is one-quarter inch.

The metal throughout is medium steel of 60,000 to 68,000 pounds per square inch tensile strength, conforming to the Manufacturers' Standard Specifications.

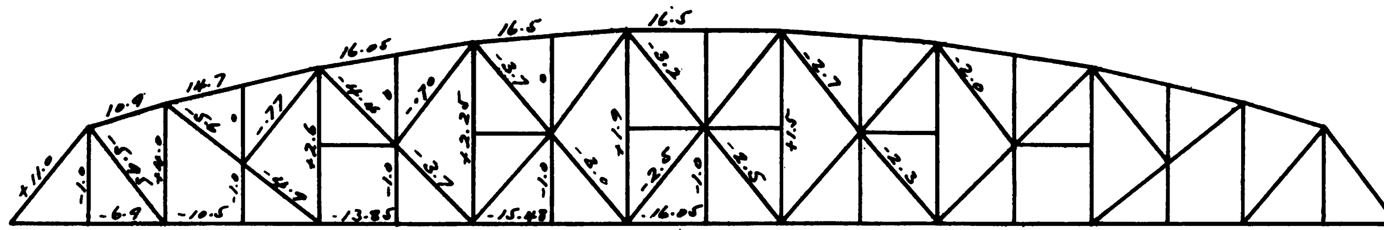
The following is a detail estimate of the material in the superstructure:

Steel	Steel pounds	Pounds per lin. ft.
Joist	185,000	315
Floor beam and hangers	83,000	142
Bracing	203,000	345
Railing	20,500	35
Shoes	24,000	41
Trusses	769,000	1,312
Total steel	1,284,500	2,190
Lumber	54,000 feet, board measure	

Loads. The assumed dead load per lineal foot of bridge used in determining the stresses, was 2,900 pounds. This includes the weight of all steel and lumber, and 300 pounds per lineal foot for snow and ice. The snow load causes no vibration or impact and was therefore classed as dead load. The effect however on the web members of a partial snow load, was considered and provided for. Wet lumber was assumed to weigh seven pounds per foot board measure. Seven-tenths of the

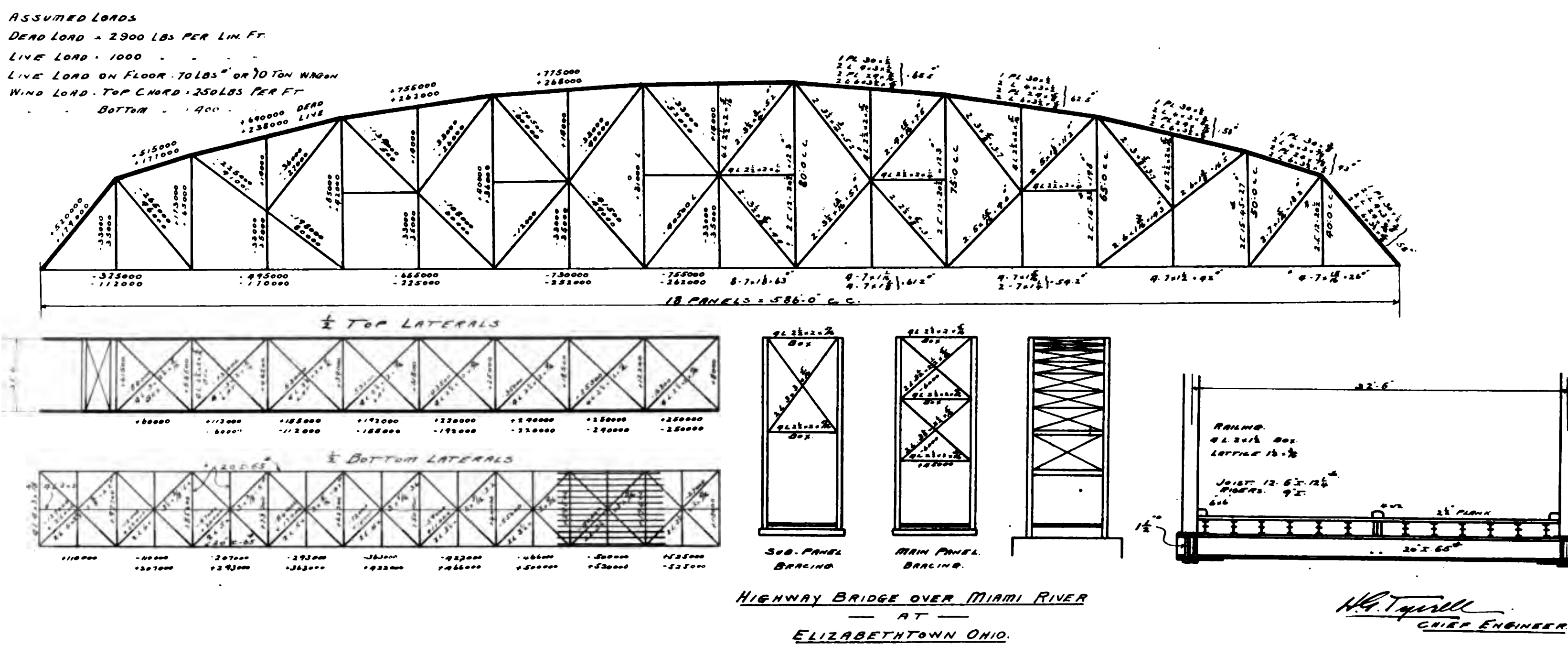


DEAD LOAD COEFFICIENTS.



PANEL 1	SHEER = 8.5
" 2	" 7.55
" 3	" 6.88
" 4	" 5.82
" 5	" 5.05
" 6	" 4.35
" 7	" 3.77
" 8	" 3.06
" 9	" 2.5
" 10	" 2.0
" 11	" 1.56
" 12	" 1.16
" 13	" .83
" 14	" .55
" 15	
" 16	
" 17	
" 18	

LIVE LOAD COEFFICIENTS.



ASSUMED LOADS
DEAD LOAD = 2900 LBS PER LIN. FT.
LIVE LOAD = 1000
LIVE LOAD ON FLOOR = 70 LBS" OR 10 TON WAGON
WIND LOAD = TOP CHORD = 250 LBS PER FT
BOTTOM = 400
18 PANELS = 586'-0" C.C.
½ TOP LATERALS
½ BOTTOM LATERALS
SUB-PANEL BRACING
MAIN PANEL BRACING
RAILING
JOIST
2½" PLANK
22'-6"
HIGHWAY BRIDGE OVER MIAMI RIVER
— AT —
ELIZABETHTOWN OHIO.
H.G. Tyrrell
CHIEF ENGINEER

entire dead load was assumed as acting at points of the bottom chord, and the remaining three-tenths at the points of the top chord.

The assumed live load was 1,000 pounds per lineal foot of bridge, for the trusses, and for the floor and its supports 70 pounds per square foot of roadway, or a ten ton road roller or wagon. These loads are all in addition to the weight of snow and ice as described above.

The wind load was taken at 30 pounds per square foot of exposed surface.

After the completion of the bridge it was the intention to remove the two river piers, one of which was already leaning over and in danger of falling.

The accompanying stress sheet shows the maximum stresses in the various members for dead, live and wind loads, and the sizes and sections used. The coefficient diagrams show the stress in the various members for panel loads of unity.

Competitive Designs. Diagrams Nos. 1 to 6, inclusive, show the truss outlines for some of the designs submitted by other engineers and bridge companies. All outlines having 22 panels or more in the trusses have evidently an excessive number of web members for economy. Number 5 has too shallow a truss, while No. 6 is too deep. Number 6, with panels 48 feet in length, was designed for a heavy system of floor framing, somewhat similar to the accepted design No. 12, excepting that in place of rolled beams for the main floor supports, plate girders were used. Each panel then became a plate girder span 48 feet in length and 30 feet in width, with several intermediate floor beams carried on the heavy side plate girders, the cross floor beams supporting steel joist. The weight of the floor system in No. 6 is excessive, due to the unusual length of truss panels. Those truss outlines have a better appearance where the curve of the top chords is uniform from end to end between the upper ends of end posts. The break in this curve at the second panel points in the upper chord, as shown in diagram No. 2, is unsightly. Number 5 has the appearance of being too flat over the central panels of the top chord.

Table of Long Span Bridges

For the purpose of comparison, a table of other long span bridges is given, arranged in the order of their length.

Date	Location	River Crossed	Kind of Bridge Railway or highway	Span ft.	Engineer
1904	Elizabethtown	Miami	Highway	586	H. G. Tyrrell
1888	Cincinnati	Ohio	Railway and Highway	550	Wm. H. Burr
1894	Louisville	Ohio	Railway	546	Phœnix Bridge Co.
1889	Cincinnati,	Ohio	Railway and Highway	542	
1896	Philadelphia	Delaware	Railway	533	
1890	Pittsburg	Ohio	Railway	523	
	St. Louis	Mississippi	Railway	524	
1885	Henderson	Ohio	Railway	522	Keystone Bridge Co.
1889	Ceredo	Ohio	Railway	521	T. K. Thomson
	Cairo	Ohio	Railway	520	Union Bridge Co.
	Havre de Grace	Susquehanna	Railway	515	
1877	Cincinnati	Ohio	Railway	515	J. H. Linville
1870	Kuilenburg	Leck River		515	G. Van Diesen
1902	New Baltimore	Miami	Highway	465	J. H. Hilton
1859	Saltash	Taular	Railway	456	Brunel
1889	Hawksbury		Railway	416	Union Bridge Co.
1901	Hamilton	Miami	Highway	406	

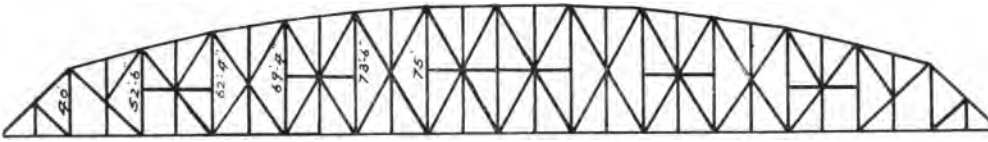
The Miami empties into the Ohio River below the City of Cincinnati. It will be seen that many of the longest spans are over the Ohio and its tributaries. In the tributaries near their mouth the high water conditions are similar to those of the Ohio River itself.

Superstructure Specifications.

The following are extracts from the general specifications under which the bridge was built:

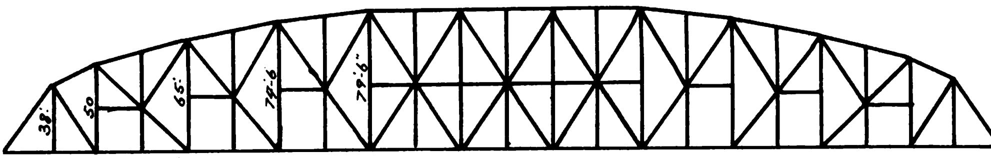
1. Headroom.—The bridge shall have a clear headroom of not less than 14 feet.

2. Material.—All framing of the bridge shall be made of wrought steel, of the grade known as Medium Steel, with an ultimate tensile strength of from 60,000 to 68,000 pounds per



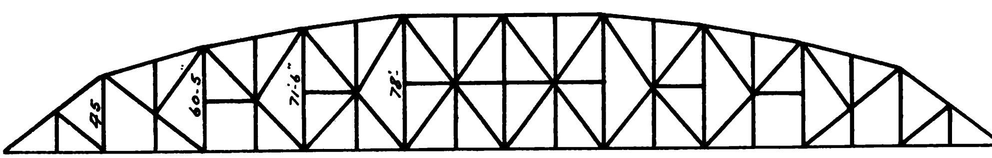
1

28 PANELS



2

22 PANELS



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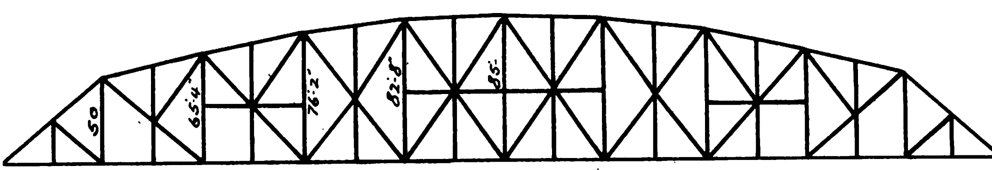
20 PANELS



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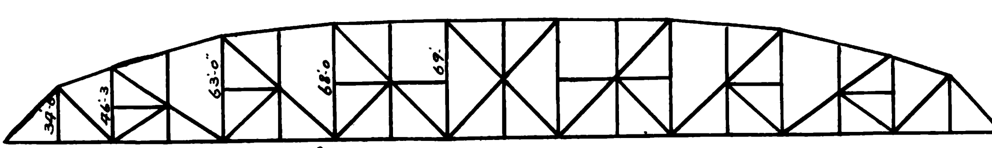
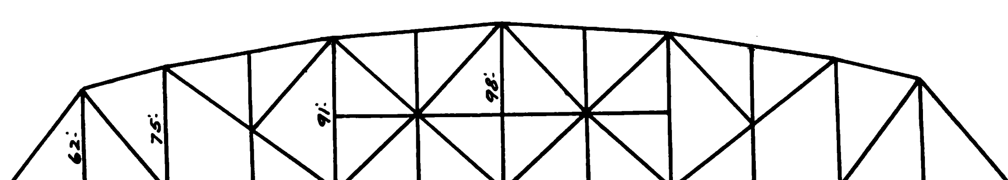
20 PANELS



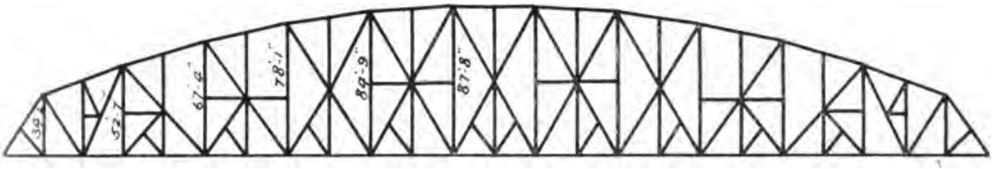
5

18 PANELS.



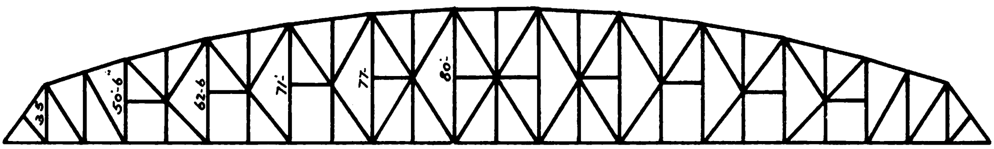
6

12 PANELS.



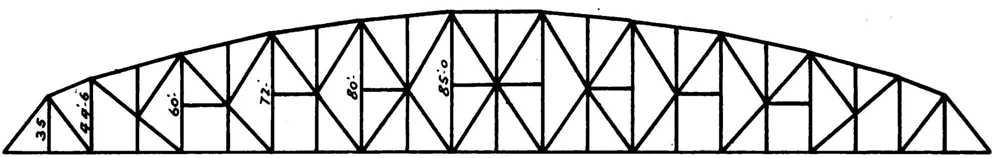
24 PANELS

7



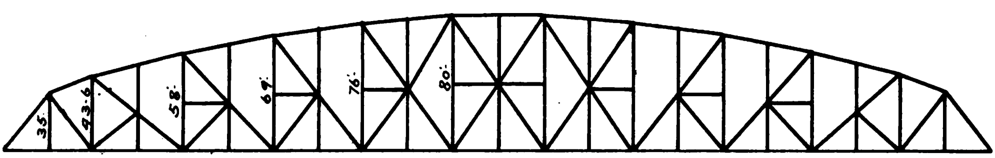
24 PANELS

8



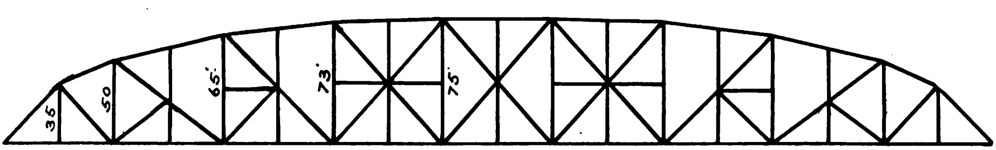
22 PANELS

9



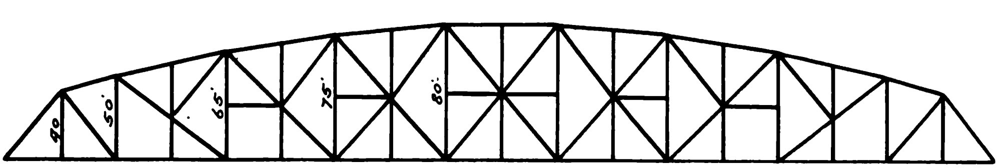
22 PANELS

10



18 PANELS

11



18 PANELS
BRIDGE AS BUILT.

12

square inch, and an elastic limit of not less than one-half the ultimate strength.

3. Flooring.—The flooring shall consist of a single thickness of oak plank, laid crosswise of the bridge and at right angles to the center line. It shall be laid in two lengths, meeting at the center, where it shall be spiked to two lines of wood joist, and the joints in the plank flooring covered by a longitudinal oak timber, dividing the width of the bridge into two separate driveways. The plank shall have a thickness not less than one-twelfth of the distance between joists. At either side of the bridge there shall be oak wheel guards not less than 4x6 inches, set up on oak blocks spaced not more than five feet apart. These wheel guards shall be bolted securely through the flooring with iron bolts with washers.

4. Loads.—In addition to the dead load of material in the bridge, it shall be proportioned to sustain a moving live load of 1,000 pounds per lineal foot of bridge and an additional load of 300 pounds per foot for snow and ice. This latter may be considered as dead load. The structure shall be proportioned for a wind load of 30 pounds per square foot, acting on the exposed surface of both trusses, and all bracing that is likewise exposed to wind pressure.

5. Unit Stresses. The permissible unit stresses shall be as follows:

	Pounds per sq. ft.	
Tension:		
Tension in eye bars	12,000	$\left\{1-\frac{\text{minimum}}{\text{maximum}}\right\}$
Tension in laterals	20,000	
Tension for combined dead, live and wind loads	25,000	
Tension in bottom flanges of solid rolled beams	12,500	

Compression:	Pounds per sq. in.
Lateral struts	$P = 13{,}000 - 60\frac{L}{r}$
Chords, live loads	$P = 12{,}000 - 55\frac{L}{r}$
Chords, dead loads	$P = 24{,}000 - 110\frac{L}{r}$
Web posts, live loads	$P = 10{,}000 - 45\frac{L}{r}$
Web posts, dead loads	$P = 20{,}000 - 90\frac{L}{r}$

In the above, P is the allowable stress per square inch in pounds.
L is the length of member in inches.
r is the least radius of gyration in inches.

No compression member shall have a length exceeding 100 times its least radius of gyration for main members, or 120 times for lateral struts.

The maximum allowable shearing stress on rivets, bolts and pins shall not exceed 10,000 pounds per square inch, the bearing stress shall not exceed 20,000 pounds per square inch, and the bending stress 25,000 pounds per square inch. Connections for field rivets shall have 25 per cent more rivets than required by the above allowable units for shop rivets.

6. Details of Construction.—Eye bars shall be so made that in testing they shall break in the body of the bar rather than in the head. Welding will not be allowed in the body of the bar. Holes shall be bored in the center of the head, and on the center line of the bar.

All bracing throughout shall be capable of resisting both tension and compression. In proportioning the sizes for lateral bracing, both systems shall be considered acting at the same time, the compression pieces resisting up to their safe capacity, and the balance of stress being carried by the tension member.

The upper lateral struts shall be the full depth of upper chord and shall be rigidly attached thereto. The lower lateral diagonals shall be connected at the panel points of the truss so that stress components from the lateral system shall be transmitted to the main truss chords. The floor beams shall be so attached that there will be no tendency towards rotation about the chord pins.

Overhead cross sway bracing shall be placed at the truss panels and this shall be as deep as head room or proper truss connections will permit. It shall be all stiff bracing, and where necessary, provision shall be made in the vertical chord posts and suspenders, to resist bending stresses from the sway bracing.

End portals shall be as deep as the necessary clearance will permit. They shall be rigidly attached to the end posts and upper chords, and proper provision shall be made in the sections of the end posts to resist the bending therein due to the action of the portal in transmitting stresses from the upper lateral system to the abutments.

Counters shall be proportioned considering that only 70 per cent of the dead load stress in the main member acts in neutralizing or counteracting the live load stress in the counter.

Long vertical tension members shall preferably be stiffened.

Riveted tension members connected to pins, shall have an excess of area through the pin holes of 25 per cent over the section of the main part.

Provision for expansion shall be made to the extent of one inch for every one hundred feet of span. There shall be at one end sets of expansion rollers not less than two and one-half inches in diameter, on which the pier boxes shall rest.

Bed plates and pier boxes shall be sufficiently large that the pressure on masonry will not exceed 400 pounds per square inch.

Splices in compression members shall have an absolutely even bearing, and shall be milled or planed. They shall have the necessary amount and number of splicing plates to properly and securely hold the sections in position.